

EAST DEVON DISTRICT COUNCIL

Tipton Vale River Erosion

Feasibility Report

Client: EAST DEVON DISTRICT COUNCIL

Job Title: TIPTON VALE RIVER EROSION

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1. INTRODUCTION

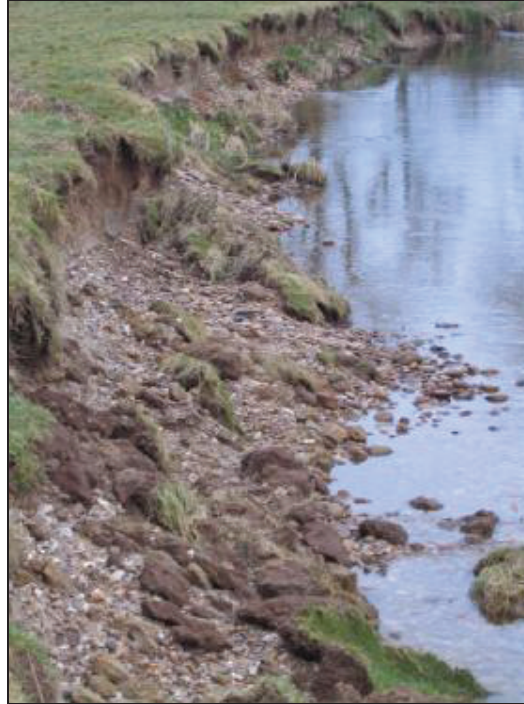
East Devon District Council's housing estate known as Tipton Vale at Tipton St John is at risk from the erosion of the right bank of the River Otter which at present is some 23m east of the estate. The land between the river and the estate is pasture and is owned by Mr. J. Carter of Fluxton. The location of the housing and the river are shown on Drawing 8041/03 in Appendix A.

The River Otter follows a long left hand bend adjacent to and upstream and downstream of the estate and erosion on the outside of this bend has been progressing over a number of years. Downstream of the estate the right bank has been protected by a steep rock armour revetment / wall constructed by the land owner Mrs Gifford of Sextons Cottage, Tipton St John. This revetment is the downstream limit of the bank considered by this report. The upstream limit is some 20m upstream of where a tributary joins the river on the right bank; upstream of this point the channel bank appears not to be eroding. The overall length of bank under consideration is 130m.

2. THE SITE

The site comprises 130m of river bank as indicated on Drawing 8041/03. It is currently eroded and is up to 2m high; a typical view is shown in Figure 2-1.

Figure 2-1 Typical Bank Profile



2.1 Survey

A survey was carried out in July 2009 by Benchmark Surveys. A copy of the survey drawing is in Appendix B. The survey comprised the bank along the site and the land behind the bank. 10. sections of the River Otter were also surveyed.

The general ground level at the site varies from 29.0m to 29.7m AOD whilst the lowest river bed level is approximately 27.0m AOD. The river bank is near vertical over the top 0.6m and then slopes steeply down to the bed. There is currently no sign of erosion of the bed on the outside of the bend.

2.2 Geotechnical Investigation

A geotechnical investigation was undertaken by Yeandle Geotechnical in July 2009. A copy of the report on the investigation is in Appendix C. The site work for the investigation comprised 3 boreholes and 3 exposures of the river bank; sieve analysis was carried out on 3 samples from the boreholes and 3 samples from the exposures. The general geological succession is given in Table 2-1.

Table 2-1 Geological Succession

Depth Range (m)	Soil	Description
Surface (0) to 0.3 – 0.8	Topsoil	Turf over medium brown sandy silt
0.3 – 0.8 to 1.0 – 2.0	Alluvium Sand	Silty fine to medium sand
.0 – 2.0 to 4.0 – 5.0	Alluvium Gravel	Medium dense to very dense

The typical grading of the gravels from the river banks was:

COBBLES	0 – 5%
GRAVEL	71 – 79%
SAND	18 – 26%
SILT and CLAY	2 – 53

Groundwater was encountered at 1.4m to 1.8m basically reflecting the river level.

2.3 The River Otter

2.3.1 Description

In the area of Tipton St John the river channel is in a wide flat floodplain which is mainly pasture or arable land. The channel banks are relatively free of vegetation. Typically the river channel is 10m to 16m wide and 2.0m to 2.5m deep and the gradient is 0.00275% (1 in 360).

2.3.2 Course of the River

Drawing 8041/04 in Appendix A shows how the position of the right bank of the river has moved since the latter part of the 19th Century. We have been advised by Ordnance Survey that the date of the most recent (OS) data – the green line – is most probably 2002; although some updating was done in 2006 they do not believe it included the river. The river therefore eroded some 10m between 2003 and 2009 when the survey was carried out. This is an average rate of 1.5m per year although the annual rate will not be constant and most erosion will occur when there are significant floods. At this rate it will take 13 years to reach the boundary of Tipton Vale.

2.3.3 Downstream Revetment

It is understood that this was originally constructed some 3 years ago. During the flood in October 2008 (reported as being the worst in 40 years) erosion of the river bed resulted in the localised failure of parts of the revetment. It is understood¹ that the bed had eroded by up to 2m adjacent to the revetment. This revetment is steep (30% to the vertical) and is constructed of blockstone.

2.3.4 Flood Flows

At the site the river has a catchment of some 188km² and the peak median annual flood flow (QMED) is 69m³/s; other peak flood flows have been estimated as follows:

Q2 (QMED)	69m ³ /s
Q5	94m ³ /s
Q10	112m ³ /s
Q20	132m ³ /s
Q30	145m ³ /s
Q50	162m ³ /s
Q100	188m ³ /s

Current recommendations are to allow for an increase of 20% in peak flood flow to cover the effects of climate change.

Flood flows have been assessed using FEH methodology utilising HI-Flows Version data and FEH CD-ROM Version 2 and WINFAP FEH Version 2 software.

¹ Rob Butcher of B. T. Jenkins Ltd - Contractors

2.3.5 River Flood Levels

A simple Hec Ras hydraulic model was developed for the surveyed reach of the river to assess the flood levels and depths for a range of flood flows. This model is very limited in its application as it takes no account of flood flows outside the incised river channel and immediate flood plain. It was used to make an assessment of the range of incised channel depths and velocities.

2.3.6 Regime

An assessment has been made of the regime condition of the incised channel using the methodology of Lacey and Simons and Albertson in CIRIA Report 551¹ and Hey and Thorne². The channel shape and gradient estimated by these methods have been compared with those of the channel immediately upstream of the site to find the method that best fits the existing channel shape and gradient. All of the methods predicted a wider and shallower channel for the normal regime 1.6 year return period flood (60 m³/s) than the existing channel. The predicted gradient was also much flatter.

Of the methods used the Hey and Thorne methodology using Type IV vegetation gave the closest match. The velocity predicted from the regime channel dimension as 2.07m/s and this agreed reasonably with a velocity of 1.81m/s from the Hec Ras model for a flow of 60 m³/s.

It is important to note that the recent construction of the revetment downstream and the proposed protection of the bank that is the subject of this study may well alter the overall regime of the river channel. Erosion of the right bank will be halted however deposition on the inside of the long bend in the river will continue until a stable channel is achieved. The channel will probably be deeper and narrower than the one that currently exists. On the basis of upstream bed levels the design bed level of the river channel has been taken as 26.80m AOD.

The design of protection works dependent on using the best possible estimate of the lowest regime bed level and it is therefore proposed that the bed level of the river in the area of the works is monitored so that any changes can be allowed for in the final design of the works.

2.3.7 Flood Scour

There will be a general lowering of the river bed as a result of the increased flow during a flood. The scour was assessed on the assumption that the area of the incised channel would increase during a flood to try and maintain the velocity that existed during a 1.6 year return period flood. The assessment gave wide variations in results depending upon which surveyed section was assessed and the flood flow considered. It is thought that much of the variation was due to the over estimation of the flow within the incised channel during extreme flood events and that this in turn resulted in an over estimation of scour. A best estimate was made using the mean channel over the length of the area of erosion; this gave a flood scour of 0.5m.

2.3.8 Bend Scour

An assessment has been made of the potential scour on the right bank of the river at the site using the various methodologies in Maynard³, CIRIA Report C551 and the US Department of Agriculture National Engineering Handbook – Part 654 Technical Supplement 14B. A total of 12 methods were considered and they gave the following ranges of values:

Maximum	3.44m
Mean	1.37m
Median	1.44m
Minimum	0.28m

¹ Manual on scour at bridges and other hydraulic structures – CIRIA - 2002

² Water Practice Manual – 7. River Engineering Part 1 Design Principles – IWEM – 1987

³ Toe-Scour Estimation in Stabilized Bendways – ASCE Journal of Hydraulic Engineering – August 1996

The extreme values were ignored and factors of safety applied where required giving the following:

Maximum	1.97m
Mean	1.67m
Median	1.80m
Minimum	0.91m

The Maximum, Mean and Median values are reasonably close to the reported total scour depth at the downstream revetment flowing the October 2008 flood (refer to Section 2.3.3). The median figure of 1.8m has been adopted for bend scour.

2.3.9 Total Scour

The total scour is the sum of flood and bend scour as assessed in the previous sections. This is the predicted depth of the bed below the regime bed level that could occur during a design flood. On the basis of a bank level of 29.60m AOD and an estimated lowest regime bed level of 26.80m AOD, the predicted level of the scoured bed on the outside of the bend will be 24.50m AOD (0.5m of flood scour and 1.8m of bend scour). This gives a bank height of 5.1m.

3. BANK PROTECTION

The bank of the river needs to be protected to prevent further erosion which could eventually put the houses at Tipton Vale at risk.

The geology (gravels and cobbles) makes the use of driven piles problematic so protection works constructed by excavation and filling techniques are the only options available. Of these there are 2 alternatives; the first based on a sloping stable river bank covered by suitable protection; the second is a battered wall similar to the revetment downstream.

The design of both these alternatives is based on a scour level of 24.50m AOD.

The following sections cover the alternative designs.

3.1 Stable Bank Option

3.1.1 Bank Slope

The Yeandle Geotechnical's Report geotechnical provide guidance on suitable stable slope as follows:

Alluvial SANDS	1 in 2	26.5 degrees
Alluvial GRAVELS	1 in 1.5	35 degrees

Generally the upper part of the river bank (top 1m) is composed of sands and thereafter there are gravels. A slope of 1 in 2 is therefore safe for the bank and has been adopted.

3.1.2 Forms of Protection

The primary bank protection can be provided in a number of ways including:

Rip-rap	graded armourstone
Gabions	wire baskets filled with stone
Concrete blocks	

Gabions have no particular advantage over rip-rap and are more costly; they also suffer from that fact that the wire forming the baskets can corrode. Concrete blocks are considered inappropriate for a rural setting so a solution based on using rip-rap as the primary protection been considered.

The primary protection will be required below water level and for the lower part of the exposed bank. Above this more natural means of protection can be used particularly towards the top of the bank. These are discussed further in Section 3.3.

For the purposes of this section of the report it is assumed that the rip-rap revetment extends over the entire river bank.

3.1.3 Rip-rap Protection

Three equations (Esarameia and May (1992) Pilarczyk (1990) and Maynord (1995))¹ have been used to assess the size of the rip-rap using the following variables:

Velocity at the toe of the bank	2.5m/s (the higher the velocity the larger the rip-rap)
Flow depth	2.0m (the greater the depth the smaller the rip-rap)
Bank slope	1 in 2
Protection	Angular rip-rap

The equations gave values for W_{50} for the rip-rap of 45, 40 and 39 kg respectively. These figures are reasonably consistent and the required revetment thickness for these sizes of rip-rap ranges from 0.43 to 0.45m. A revetment thickness of 0.45m has therefore been adopted with a W_{50} of 45 kg.

Details of the proposed revetment are shown as Option 1 on drawing 8041/05 in Appendix A . The dimensions and details have been established using the methodology in the "Manual on scour at bridges

¹ Manual on scour at bridges and other hydraulic structures – CIRIA - 2002

and other hydraulic structures – CIRIA – 2002”. Instead of extending the revetment down to the predicted scour level a “Falling Apron” has been adopted. This is a rip-rap apron at the toe of the bank that will fall into holes that are scoured in the bed and will protect the bank face of the scour hole from erosion. The volume of the falling apron has been assessed on the basis that scour could extend to the maximum scour level of 24.5m AOD).

It should be noted that the design of the rip-rap is controlled by the velocity and any change can radically alter the mass of the stone required. The velocity of flow in the river should be monitored in flood conditions to enable the design velocity to be confirmed.

3.2 Battered Wall Option

A battered wall has the advantage of minimising land take when compared to a stable slope solution. It is similar to the form of construction used downstream of the site but is designed to be more stable.

3.2.1 Forms of Wall

Walls can either be gravity structures which rely on their mass for stability or cantilever type that rely on the weight and or resistance of the soil for support. Cantilever walls are sophisticated engineering structures that use the minimum of land but are expensive to construct; they are not suitable for river banks particularly in a rural location. Gravity walls can either be of mass concrete or masonry construction acting as homogeneous structures or of dry-stone construction comprising individual stones placed to form a stable structure. It is considered that the dry-stone form of construction is the most suitable for a river bank and has been adopted for consideration in this report.

3.2.2 Dry Armourstone Wall

The wall would be designed as a gravity structure and would comprise cuboid armourstone dry bedded in layers to form a stable structure. The proposed design is shown as Option 2 on drawing 8041/05 in Appendix A. It would be founded at the scour level of 24.50m AOD and would need to be 2.0m thick to maintain its stability. Cuboid armourstone would have to be used to ensure that each stone is soundly bedded on the ones underneath. There would be no material between each stone; they would rely on friction to keep them in place. Smaller stones and soil would be introduced to fill voids and encourage plants to grow. The size of the armourstone is not critical but to give an acceptable appearance they would have to be reasonably large (at least 500kg).

Again it has been assumed in this section of the report that the wall extends for the full height of the bank, however this does not necessarily have to be the case and other methods of secondary protection can be incorporated towards the top of the bank above normal river levels.

3.3 Alternative and Composite Protection

The primary form of protection will have to be either rip-rap or a battered dry armourstone wall as discussed in the previous sections of this report. These are hard forms of construction and, if continuous, produce features that are not natural to a river bank particularly in a rural setting. It is possible to use the primary protection in the lower parts of the bank and use more natural means of protection towards the top of the bank. In fact a variation on the form of protection can be adopted along the river bank to improve the overall appearance.

Secondary forms of protection are invariably based on encouraging plants (usually willow) to grow to reinforce and protect soil. Ledges and berms can be incorporated to vary the shape of the river bank and encourage particular plants to grow. It will also most probably be necessary to use a stone filter instead of geotextile as a filter and separation layer to allow roots to penetrate to the underlying soil.

One possibility is shown on drawing 05 in Appendix A for composite protection.

4. COSTS

Table 4-1 details the costs associated with the construction of the two options for protecting the river bank.

Table 4-1 Capital Costs

	Rip-Rap Option	Wall Option
Bed level and flood flow velocity monitoring	£2,000	
Design (10% of Construction Costs)	£13,000	£16,000
Consultations* (40 man hours at £60/hr)	£2,400	£2,400
Consents and Permissions (20 man hours at £60/hr)	£1,200	£1,200
Tender Documents and Tender Processes (5% of Construction Cost)	£6,500	£8,000
Construction	£130,000	£160,000
Construction Contract Administration (5% of Construction Cost)	£6,500	£8,000
Site Supervision (5% of Construction Cost)	£6,500	£8,000
Land costs – purchase and or compensation (nominal sum)	£2,000	£2,000
Sub-total	£170,100	£205,600
Optimism Bias – Contingency (30% of Sub-total)	£51,030	£61,680
Total	£221,130	£267,280

* With East Devon District Council Planning Department, the Environment Agency, the land owner and any other interested parties that may be consulted by EDDC and / or the EA.

The Optimism Bias allows for uncertainty in the design and costing at this stage.

5. IMPLEMENTATION

5.1 Permissions and Consents

East Devon District Council planning department has confirmed that as the works will be engineering works planning permission will be required.

The Environment Agency has confirmed that Land Drainage Consent will be required for both the temporary works required during construction and for the permanent works.

The need to obtain these permissions and consents will mean that it will be necessary to address environmental issues and the visual impact of the works when producing the design and will require consultation with interested bodies. An allowance has been included for this in the cost estimates

5.2 Land

Permission will be required from the land owner (Mr Carter) to carry out the works and any requirements that he has will have to be incorporated into the design and arrangements for construction. It should be noted that the works will be in his interests as without them his land will continue to be eroded and lost. It seems reasonable therefore that he will co-operate. A nominal sum has been included for the payment of compensation; however this may not be necessary.

It will be necessary to draw up an agreement with the land owner to permit the construction and to cover maintenance and repair of the works (see Section 5.4).

The Council is advised to obtain specialist assistance in negotiations regarding compensation and in drawing up any necessary agreements.

5.3 Construction

The work should be undertaken by a contractor with experience of river works, particularly if environmentally compatible measures are incorporated. The works will fall under the CDM regulations and a Planning Co-ordinator will need to be appointed.

Special consideration will have to be taken of:

- The overhead power lines adjacent to the river bank
- Access to the site for the delivery of plant and materials and the off-site disposal of any surplus excavated material. With regard to this latter point the EA have advised that they will not allow material to be tipped into the river channel or the flood plain and that any surplus material will have to be disposed of outside the flood plain of the river.
- Pollution of the River

5.4 Maintenance

It will be necessary to monitor the performance of the protection measures particularly after a flood and to undertake any necessary remedial works.

The main requirements will be to ensure that the revetment or wall remains stable and that scour is within the design allowance.

If planting is incorporated into the works it will be necessary to maintain it. This could include regular coppicing (3 to 5 years) of willows etc.

It will be necessary to establish responsibilities for inspections, monitoring and maintenance and repair with an appropriate division between the Council and the land owner.

6. CONCLUSIONS AND RECOMMENDATIONS

- 1) The right bank of the River Otter is eroding at an average rate of 1.5m per year and at this rate will reach the boundary of the Tipton Vale housing in 13 years.
- 2) It has been assessed that the bed of the river adjacent to the right bank could erode to a depth of approximately 2.3m below general bed level during a flood; this is in line with observations immediately downstream following the October 2008 flood. Protection works will have to allow for this erosion.
- 3) It is recommended that bank protection is used to prevent further erosion and that this should be primarily in the form of a rip-rap laid on a stable bank (at a slope of 1 in 2) and that a falling apron should be used to protect the bank face of scour holes at the tow of the bank.
- 4) It is recommended that the upper part of the slope should be protected in environmentally-acceptable and sustainable ways using vegetation (willows, etc.) and that the overall form of the bank and the protection should be designed to achieve a natural river bank.
- 5) The budget for the protection works is estimated to be £221,130.
- 6) It is recommended that the bed level of the river is monitored so that any changes in bed level can be recorded and used to establish an appropriate design bed level.
- 7) It is recommended that flood flow velocities are monitored in the river prior to finalising design to enable the mass of the rip-rap to be confirmed.

APPENDIX A – DRAWINGS


Drawing 8041/03	Location Plan
Drawing 8041/04	Historic Right Bank Alignment
Drawing 8041/05	Proposals

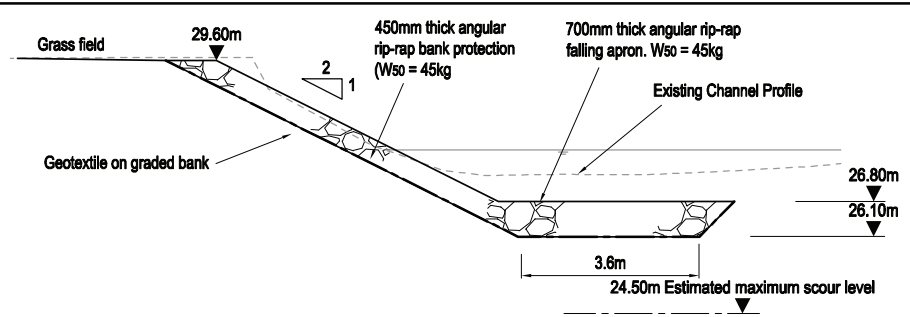
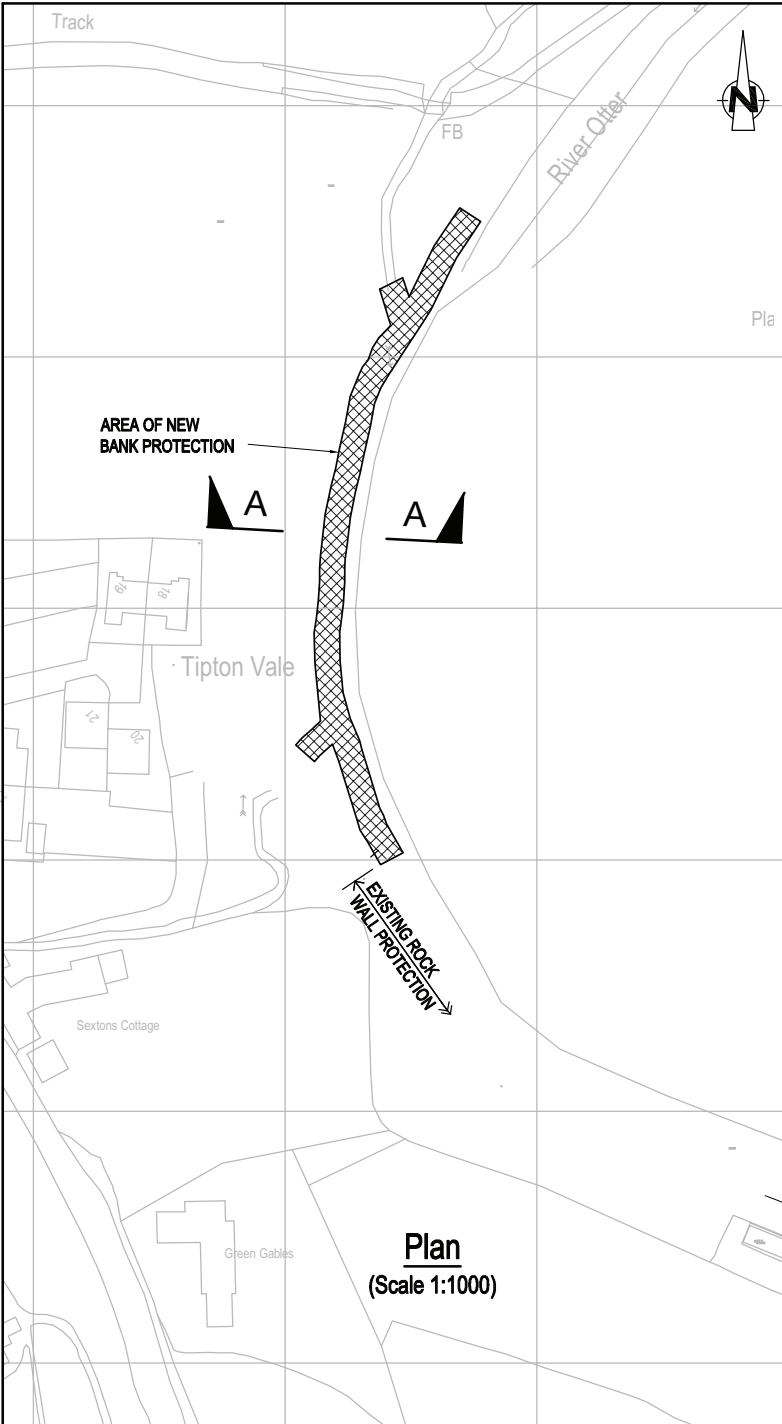
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- Survey 2009
- - - Assumed
- Most recent OS mapping

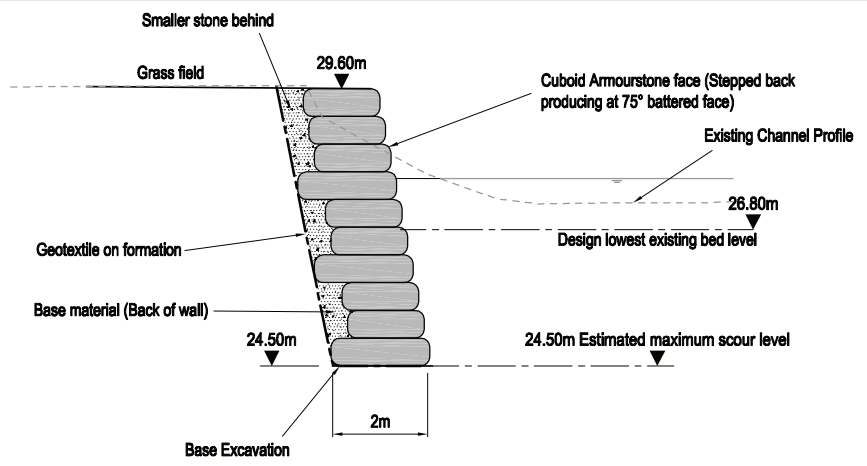


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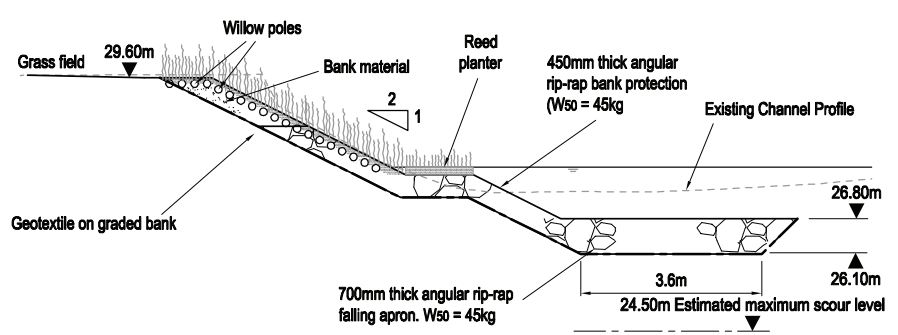
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 2, Silverdown Office Park, Fair Oak Close, Clyst Honiton, Exeter, EX5 2JX Tel: 01392 360301, Fax: 01392 363883 E-Mail: office@howick.uk.com, website: www.howick.uk.com					
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Section A-A (Option 1 - Riprap)
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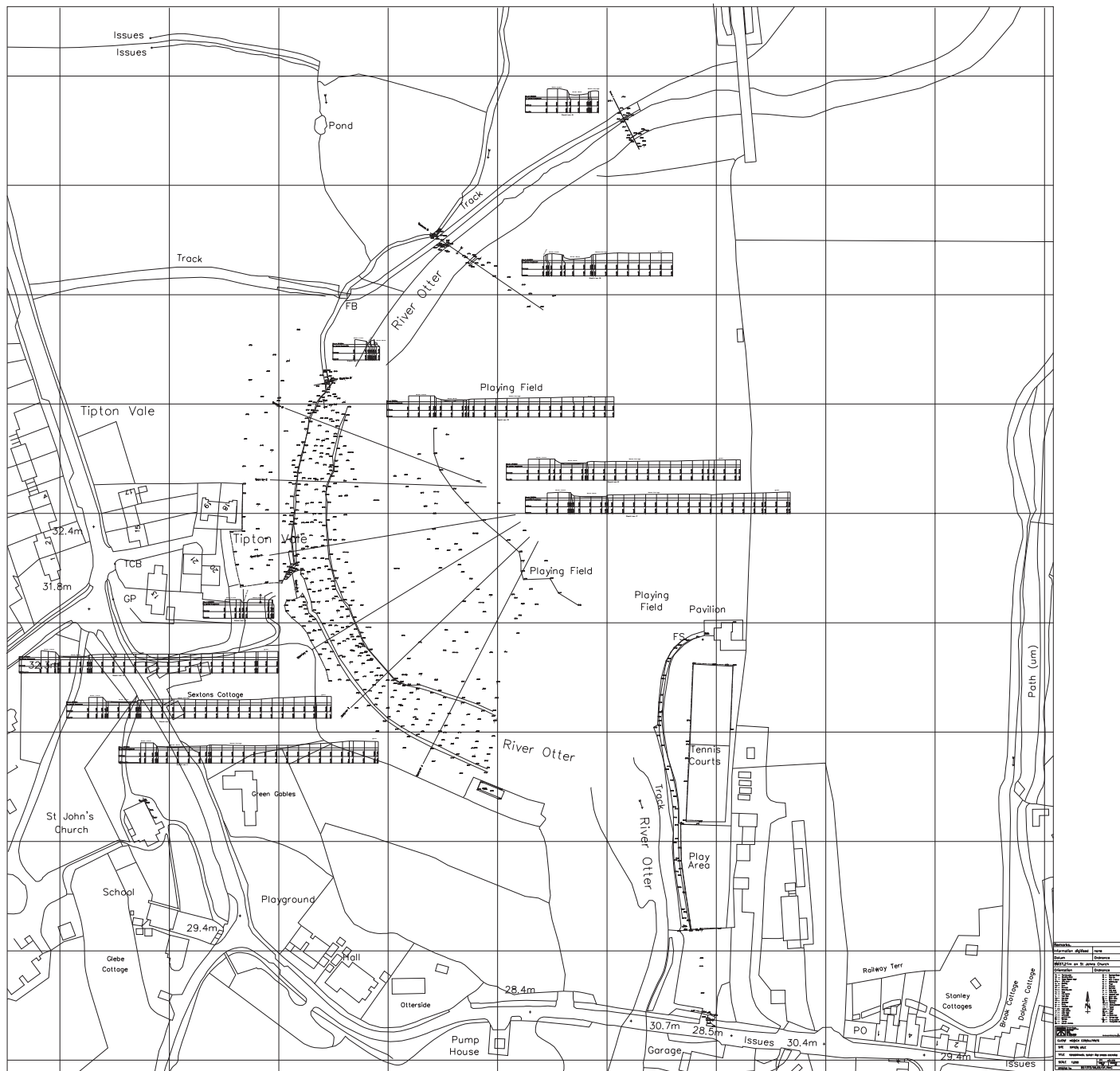
Section A-A (Option 2 - Armourstone Wall)
(Scale 1:100)



Section A-A (Alternative)
(Scale 1:100)

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2, Silverdown Office Park, Fair Oak Close, Clyst Honiton, Exeter, EX5 2UX Tel: 01392 360301, Fax: 01392 363883 E-Mail: office@howick.uk.com, website: www.howick.uk.com				
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APPENDIX B – TOPOGRAPHICAL SURVEY



APPENDIX C – GEOTECHNICAL INVESTIGATION

**TIPTON VALE, TIPTON ST JOHN
RIVER OTTER BANK EROSION**

GEOTECHNICAL REPORT

CLIENT: EAST DEVON DISTRICT COUNCIL

ENGINEER: HOWICK CONSULTANTS

CONTRACT: BC7893

AUGUST 2009

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APPENDIX 1: British Geological Survey Historical Records

APPENDIX 2: Site Photographs

APPENDIX 3: Cable Tool Borehole Records

APPENDIX 4: Laboratory Test Results

APPENDIX 5: Borehole Location Plan

1.0 INTRODUCTION

Yeandle Geotechnical Ltd (YGL) were commissioned by Howick Consultants, acting on behalf of East Devon District Council, to undertake a geotechnical investigation at Tipton Vale, Tipton St John, in an area close to the River Otter where significant and progressive river bank erosion is occurring.

The purpose of the investigation was to establish the ground conditions to enable design and construction of appropriate protection works to safeguard a number of properties at the eastern end of Tipton Vale.

2.0 THE SITE

The area investigated is on the western side of the River Otter, between two small tributary streams which enter the River Otter on the western side. The length of river bank in question is approximately 90m and is subject to significant and progressive erosion, which has possibly been exacerbated by erosion protection works immediately downstream.

Some selected site photographs are enclosed as Appendix 2, and show some general views of the site and the active erosion.

3.0 GEOLOGY AND HISTORICAL RECORDS

3.1 Geology

Published Geological Survey Map Sheet 326, Sidmouth, 1:50,000 series – Solid and Drift, indicates that the site is underlain by Recent Alluvium (*silt, sand and clay, overlying gravel*), with some undifferentiated River Terrace Deposits (*gravel with sand, silt and clay*) and Peat just to the west of the area investigated. These Terrace Deposits are of Holocene, Quaternary age.

The Alluvium and Terrace deposits are in turn underlain by the Otter Sandstone Formation of Anisian, Middle Triassic age. The Otter Sandstone Formation is described as “*Sandstone, reddish and yellowish brown, grey and greyish green, fine-to medium-grained, weakly cemented, with thin beds of hard conglomerate and a few lenticular beds of reddish brown mudstone*”. The Otter Sandstone can be up to 210m thick.

3.2 YGL Records

In January/February 2005 YGL undertook geotechnical investigations at Fluxton STW which is approximately 0.5km north of the area investigated. The investigations were undertaken for South West Water Services Ltd and involved the excavation of three trial pits and one Cable Tool borehole. The geology, namely Alluvium over Triassic strata, is similar to geology at the Tipton Vale Site. The following strata were encountered:

Stratum	TP1	TP2	TP3	BH1
Topsoil/Made Ground	GL – 0.3	GL – 0.35	GL – 0.8	GL – 0.8
Alluvial Clay*			0.8 – 2.2	0.8 – 1.1
Alluvial Gravel**	0.3 – 2.0	0.35 – 2.4	2.2 – 3.0	1.1 – 5.0
Head ?				5.0 – 6.0
Triassic Strata***				6.0 – 9.65
Groundwater	1.5 and 1.8	1.8	2.8	1.8

- * Firm becoming soft
- ** Generally medium dense
- *** Mudstones to 8.0m then Sandstones

3.3 BGS Records

As part of the study, YGL contacted the British Geological Survey to obtain any relevant available historical exploratory hole records held by the BGS. A plan from the BGS GeoIndex database and list of borehole records is enclosed in Appendix 1, together with selected records which were purchased from the BGS. Unfortunately, it is not possible to access the records prior to purchase, and the records obtained are actually of little use. The records obtained are also enclosed in Appendix 1, and are detailed as follows:

BGS ID 717389. Tipton 5A: This was a 28.68m water supply observation borehole drilled prior to 1966, and the strata are simply recorded as Alluvium over Otter Sandstone. It appears that a pumping test was undertaken in 1977 at which time the water level was recorded as artesian at 0.5m above ground level.

BGS ID 717423. Council Houses, Tipton St John: This is a water supply borehole drilled by W Shepherd & Sons in July 1949. The borehole was drilled to 30.2m and encountered the following:

GL – 0.6m	Subsoil
0.6 – 7.3m	Sand and Pebbles (buff coloured)
7.3 – 7.6m	Gravel
7.6 – 12.2m	Red Clay
12.2 – 27.4m	Red Sand Rock
27.4 – 29.6m	Red Clay and Sand
29.6 – 30.2m	Pebbles

It appears that the water level in this borehole was recorded at 0.41m in March 1977, and the borehole is shown to be at 4 Tipton Vale.

BGS ID 717398. Tipton Lodge No. 1: This is a record of a shallow well 2.15m deep, with a standing water level at 0.485m in March 1977.

BGS ID 717399. Tipton Lodge No. 1: This is also a record of a shallow well 2.1m deep, with a standing water level at 0.42m in March 1977. The estimated log is shown as Alluvium over Otter Sandstone.

4.0 FIELDWORK

Between 30 June and 2 July 2009, three (3 No.) Cable Percussive boreholes were drilled to establish the ground conditions at locations selected by Howick Consultants. Originally, it was intended to drill five boreholes, but budget constraints restricted the investigation to three boreholes. The three boreholes drilled were located essentially at three of the original intended positions, although the locations were somewhat dictated by overhead power cables.

Boreholes 1 and 2 were drilled close to the river bank, with BH1 upstream and BH2 downstream. BH3 was drilled further back from the river bank at the southern end of the area investigated, towards the properties in question. BHs 1, 2 and 3 achieved depths of 6.80, 6.72 and 6.74m below existing ground level respectively, with each borehole terminating in weathered Otter Sandstone.

During the course of drilling, in-situ Standard Penetration Tests (SPTs) were undertaken at regular and frequent intervals to obtain a measure of the in-situ relative density of the granular soils penetrated. SPTs were also undertaken to obtain a measure of the strength of the weathered bedrock at depth. Small and bulk disturbed samples were obtained at frequent intervals for logging and classification purposes.

The boreholes were generally terminated following a minimum of two SPT-N values >> 50. The gravels were particularly dense, and chiselling techniques were required to advance the boreholes through the dense and very dense gravels. Chiselling was also used to advance BH3 through the Otter Sandstones.

When groundwater was encountered, drilling operations were suspended for 20 minutes and the rate of ingress recorded.

The Cable Percussive Borehole Records are enclosed as Appendix 3, and in addition to detailed strata descriptions also give information on progress, groundwater, samples recovered and the results of in-situ SPTs. The ground levels shown on the Borehole Records have been interpolated from spot levels shown on the topographical survey plan supplied by Howick Consultants.

The Borehole Location Plan is enclosed as Appendix 5 and is based on the topographical survey plan supplied by Howick Consultants.

5.0 GROUND CONDITIONS

5.1 Geology

As discussed in Section 3.1, the geology beneath the site was expected to comprise Recent Alluvium over Otter Sandstone.

5.2 Strata Encountered

For full information on the strata encountered at the individual exploratory borehole locations, reference should be made to the Borehole Records in Appendix 3.

The investigation encountered the expected ground conditions, with Topsoil over Alluvium, which in turn is underlain by the Otter Sandstone.

The strata encountered in each borehole is detailed as follows:

<i>Strata</i>	<i>BH1</i>	<i>BH2</i>	<i>BH3</i>
<i>Topsoil</i>	GL - 0.3	GL - 0.8	GL - 1.0
<i>Alluvium - Sand</i>	0.3 - 1.0	0.8 - 1.3	1.0 - 2.0
<i>Alluvium - Gravel</i>	1.0 - 4.2	1.3 - 5.0	2.0 - 4.0
<i>Otter Sandstone</i>	4.2 - 6.80	5.0 - 6.72	4.0 - 6.74
<i>Groundwater</i>	uncertain	1.8	1.7

Topsoil

Topsoil was encountered to depths of between 0.3 and 0.8m comprising turf over medium brown sandy silt.

Alluvium - Sand

A layer of silty, fine to medium SAND was encountered extending to total depths between 1.0 and 2.0m. In BH3 this material was seen to contain a little gravel. A SPT-N value of 5 was recorded in BH3.

Alluvium - Gravel

The alluvial gravels were seen to extend to total depths of between 4.0 and 5.0m. The gravels were seen to be medium dense, dense and indeed very dense, and chiselling techniques were required to penetrate the gravels in BHs 1 and 2. Chiselling techniques were required not only because of the density of the gravels, but also the presence of quartzite cobbles. From the boreholes the gravels have been described as sandy and with a little to some cobbles. More accurate descriptions of the gravels were obtained from grading analyses on samples obtained from the river bank exposures (see Section 6), and the three grading analyses indicate the following:

COBBLES		0 – 5%
Fine medium coarse GRAVEL		71 – 79%
SAND		18 – 26%
SILT and CLAY		2 – 3%

SPT results in the alluvial gravels are as follows. Unless otherwise stated, the figures are for blows per 75mm.

BH1	1.0 – 1.450m	2, 3, 4, 5, 6, 7	N = 22
	2.0 – 2.450m	3, 4, 4, 4, 6, 8	N = 22
	3.0 – 3.450m	21, 12, 6, 13, 13, 9	N = 41
BH2	2.0 – 2.425m	2, 3, 7, 11, 19, 13 for 50mm	
	3.0 – 3.425m	12, 12, 11, 11, 15, 13 for 50mm	
	4.0 – 4.295m	3, 6, 24, 26 for 70mm	
BH3	2.0 – 2.450m	5, 5, 6, 7, 8, 10	N = 31
	3.0 – 3.450m	3, 4, 4, 5, 5, 7	N = 21

Otter Sandstone

Otter Sandstone was encountered in each of the boreholes below depths of between 4.0 and 5.0m, to their full depth, typically comprising weak fine to coarse grained SANDSTONE weathered to medium dense becoming dense sand, particularly in BH1.

SPT results within the Otter Sandstone are as follows:

BH1	5.0 – 5.450m	3, 5, 7, 8, 5, 3, N = 23
	6.5 – 6.785m	10, 14, 23, 27 for 60mm
BH2	5.0 – 5.350m	7, 13, 14, 20, 16 for 50mm
	6.5 – 6.720m	9, 16, 50 for 70mm
BH3	4.0 – 4.285m	6, 12, 13, 37 for 60mm
	5.0 – 5.200m	12, 15, 50 for 70mm
	6.5 – 6.740m	15, 10 for 60mm, 35, 15 for 30mm

It should be noted that in BH1 a SPT was undertaken across the boundary between the alluvial Gravel and Otter Sandstone from 4.0 – 4.45m, with a SPT-N value of 12. Similarly in BH2 a SPT was undertaken across the boundary between the alluvial Sand and alluvial Gravel with a SPT-N value of 11.

5.3 Groundwater

Groundwater was encountered in the boreholes as follows:

- BH1 Depth of water strike uncertain as water was added to borehole below 1.5m to assist drilling through Gravels. Groundwater probably at approximately 1.8m.
- BH2 Struck at 1.8m rising to 1.7m in 20 minutes and not sealed by drill casing. Groundwater standing at 1.6m after pulling casing.
- BH3 Struck at 1.7m rising to 1.5m in 20 minutes and not sealed by drill casing. Groundwater standing at 1.4m after pulling casing.

6.0 RIVER BANK EXPOSURES AND SLOPES

As part of the geotechnical study, YGL logged the river bank exposures. A series of photographs were taken which are enclosed as Appendix 2. The photographs clearly show the active erosion and the strata exposed formed three basic units, namely topsoil, an upper layer of alluvial Sand and then a layer of alluvial Gravel. The alluvial Gravels form the river bed. As previously discussed, samples of the alluvial Gravels were excavated from the exposures to enable more representative grading analyses than would have been possible from borehole samples. The depth to the interface between the alluvial Sands and the alluvial Gravels varies from approximately 0.45 to 0.9m. The boundary between the topsoil and the alluvial Sands is gradational, and largely based on a colour change, rather than lithological differences. The strata at the three logged exposures are as follows:

Section 1: **Close to downstream end of site out from BH3.**
GL – 0.25m Turf over light brown, very silty, very sandy TOPSOIL.
0.25 – 0.55m Pale yellow brown, mottled grey brown, silty fine-medium SAND.
0.55 – river level Slightly silty, very medium-coarse sandy, fine-medium-coarse rounded to sub-angular GRAVEL. (Sample 1)

Section 2: **Adjacent to BH2.**
GL – 0.25m Turf over light brown, very silty, very sandy TOPSOIL.
0.25 – 0.9m Pale yellow brown, mottled grey brown, silty fine-medium SAND.
0.9 – river level Slightly silty, very fine-medium-coarse sandy, fine-medium-coarse rounded to sub-angular GRAVEL with some cobbles. (Sample 2)

Section 3: **Adjacent to BH1.**
GL – 0.25m Turf over light brown, very silty, very sandy TOPSOIL.
0.25 – 0.45m Pale yellow brown, mottled grey brown, silty fine-medium SAND.
0.45 – river level Slightly silty, very medium-coarse sandy, fine-medium-coarse rounded to sub-angular GRAVEL. (Sample 3)

Future protection works could involve re-grading the river bank to an appropriate angle, with the re-graded slope extending possibly to some 2.0m below river bed level. Therefore, the re-graded slopes would be largely within the alluvial Gravels, with a layer of alluvial Sand forming the upper part of the slope. The stability of such slopes is dependent on a number of variables, including slope angle, pore water pressures and slope height.

Using recognised correlations between SPT-N values and angle of internal shearing resistance (ϕ) it is recommended that the upper part of the slope which will be within the alluvial Sands could be graded to an angle of 1V:2H (c.26.5°). SPT-N values within the alluvial Gravels are variable, with an average N value of 27 from the five tests which were driven the full standard distance. It should be noted that three SPTs within the alluvial Gravels did not achieve full penetration, and therefore this average N value of 27 is probably somewhat lower bound. A re-graded angle of 35° is considered appropriate for the alluvial Gravels. It should be noted that these recommended slope angles do not take into account erosive forces from the river itself, and it is understood that if the re-graded slope option is undertaken, appropriate erosion and scour protection will form part of the works.

7.0 LABORATORY TESTING AND PERMEABILITIES

The following laboratory tests were scheduled by YGL and undertaken on selected samples obtained from the boreholes, and river bank exposures:

Particle Size Distribution – coarse (wet sieve) 6 No

Laboratory test results are enclosed in Appendix 4, and testing was undertaken in accordance with BS 1377 "Methods of Tests for Soils for Civil Engineering Purposes" 1990 in a UKAS accredited laboratory.

As detailed in Section 5.2, the three grading analyses for the alluvial Gravels are summarised as follows:-

COBBLES		0 – 5%
Fine medium coarse GRAVEL		71 – 79%
SAND		18 – 26%
SILT and CLAY		2 – 3%

These results show relatively small variations in grading, although it would be expected that there is an appreciably higher cobble content in parts, as many cobbles are present on the river bed. It would be expected that the alluvial Gravels are of high permeability, with the groundwater within the gravels being in hydraulic continuity with water levels in the River Otter. It would also be expected that there would be some time lag between variations in river level and associated response within the alluvial Gravels. The time lag would be a function of permeability.

Published information suggests that permeabilities for sand and gravel mixtures are in the general range of $k = 10^{-2}$ to 10^{-4} m/s (reference BS 8004 : 1986). Hazen's formula can also be used to give a very approximate guide to permeability based on grain sizes and uniformity coefficients. On the basis of the three grading analyses, permeabilities in the order of 3×10^{-3} to 7×10^{-4} m/s have been calculated using Hazen's formula. It should be noted that Hazen's formula is based on sands, and is not strictly applicable to coarser grained mixtures. Therefore, these values are for general guidance and should be used accordingly.

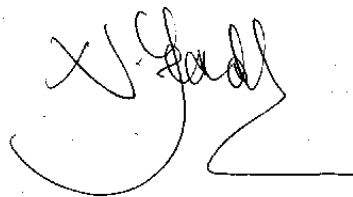
8.0 GEOTECHNICAL DISCUSSION

The main findings of the investigation are as follows:

- Relatively consistent ground conditions.
- Topsoil to 0.25/0.3m. Locally deeper to 0.8/1.0m.
- Alluvial SANDS to 1.0/2.0m (boreholes) and to 0.45/0.9m (river bank).
- Alluvial SANDS loose and loose to medium dense.
- Alluvial GRAVELS to 4.0/5.0m (boreholes).
- Alluvial GRAVELS medium dense to very dense with some cobbles.
- Otter Sandstone below 4.0/5.0m generally very weak and weathered to medium dense sand in upper levels of BH1.
- Groundwater in alluvial Gravels at 1.7/1.8m, in direct hydraulic continuity with River Otter.
- Alluvial GRAVELS would form a suitable bearing stratum for bank protection works.
- Re-graded slopes of 1V:2H (c. 26.5°) considered appropriate for the alluvial Sands, and 35° for the alluvial Gravels.
- Alluvial GRAVELS are, in parts, very dense with cobbles of quartzite, and it would be difficult to drive sheet piles through this stratum on the basis of the boreholes which, in parts, required chiselling techniques to penetrate the Gravels.



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